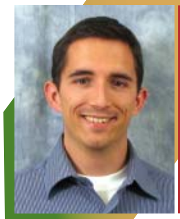
Photonic Doppler Velocimetry



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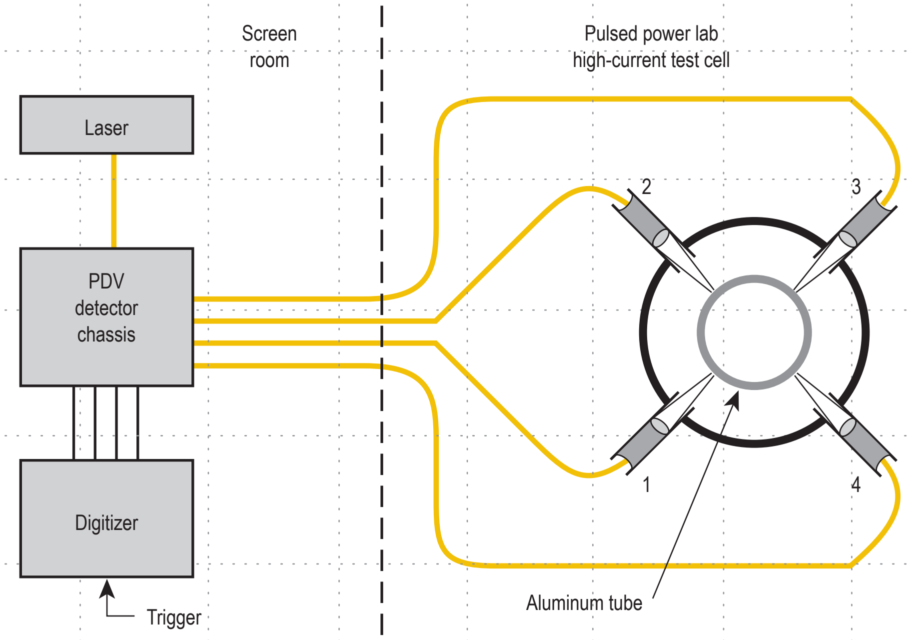
Optical velocimeters are noncontact diagnostics widely used to measure the velocities of explosively driven metal surfaces in single-shot shock physics experiments. Photonic Doppler Velocimetry (PDV) is a novel optical velocimetric technique, developed at LLNL, that uses optical heterodyning to measure the beat frequency between light incident on and light reflected by a moving metal surface. In this project, we have used PDV in an atypical role on the coaxial load experiment with ALE3D.

Project Goals

Our goal was to use PDV on the ALE3D coaxial load experiment to provide velocity and displacement versus time data for four locations on the sidewall of an aluminum tube during the electromagnetically induced collapse of the tube. The measured PDV data would be used to validate and critique modeled results from ALE3D, an LLNL multiphysics hydrocode.

Figure 1. Block diagram of PDV system and probe layout. An optical circulator and power splitter within the PDV detector chassis routed optical power from the laser, to the probes, and into the detectors.



Relevance to LLNL Mission

Velocimetry is one of the primary shock physics diagnostics. PDV is a particularly attractive diagnostic for experiments involving significant quantities of radiated electromagnetic energy or high-explosives because 1) the PDV probes and fibers that are exposed in the experimental environment are immune to electromagnetic interference; 2) PDV requires no direct mechanical contact with the measurement surface; and 3) PDV does not require any electrical connections to be made on or near the measured surface. Specific programs requiring this expertise include explosive pulsed power for high-energy-density physics research, high-velocity impact experiments for materials, EM launcher/shaker experiments for military applications, and subcritical component testing.

FY2007 Accomplishments and Results

Four PDV probes were installed on the ALE3D coaxial load testbed to monitor the motion of the tube at four azimuthal positions separated by 90° at the mid-plane of the tube (Fig.1). The interface between the PDV probes and coaxial load test stand were machined adapters that were locally designed and fabricated.

The PDV laser transmitted 1550-nm light over optical fiber to each PDV probe. A fraction of light incident on the fiber endface inside the probe

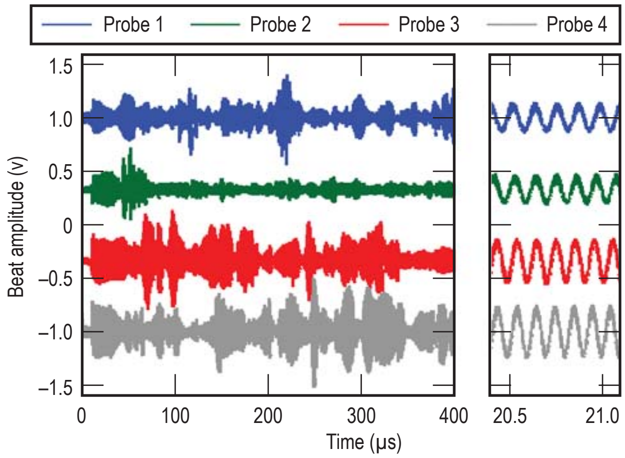


Figure 2. Raw PDV data. The beat frequency is clearly visible in the plot on the right, which depicts only a small sample in time (between 20.0 and 20.5 μs) of the total waveform on the left. The waveforms are offset vertically to improve visibility.

was reflected back along the fiber; a comparable amount was launched by the probe onto the moving tube surface, reflected and Doppler-shifted, and collected by the probe to also return along the fiber.

Both the endface reflected (unshifted) and reflected Doppler-shifted signals were coupled via an optical circulator onto the detectors. The beat signal (a signal that is amplitude modulated at a frequency equal to the difference in frequency between the two reflected signals) was recorded and digitized. With unshifted light at 1550 nm, this beat frequency corresponds to 1.29 MHz per 1 m/s surface velocity. The maximum velocity detectable by the PDV system we used was around 5 km/s, limited by the bandwidth of the detectors and digitizers, and well beyond our expected needs.

PDV data were taken on five shots of the ALE3D coaxial load experiment. Figure 2 shows raw data from one shot. The raw data, representing the beat waveform, is processed using a sliding Fast Fourier Transform (FFT) to determine beat frequency as a function of time. The transformed data are scaled by 1 m/s per 1.29 MHz to provide velocity versus time data, and integrated with respect to time to provide displacement versus time data. The processed velocity and displacement data are shown in Fig. 3.

Our application of PDV was slightly unusual due to the low surface velocities measured—tens of meters per second rather than kilometers per second. We experienced no difficulty measuring these relatively low velocities.

In addition, our experiment confronted one of the disadvantages of PDV, that the magnitude of the Doppler shift can be detected, but not the direction of surface movement. Although this problem was prevalent in our data due to the oscillatory response of the tube walls, the issue was minimized by assuming that after the initial compression, each velocity zero corresponded to a reversal in direction of motion. These assumptions were supported by data from auxiliary diagnostics.

Related Reference

Strand, O. T, D. R Goosman, C. Martinez, T. L. Whitworth, and W. W. Kuhlow, "A Novel System for High-Speed Velocimetry Using Heterodyne Techniques," *Rev. Sci. Instrum.*, **77**, 083108, 2006.

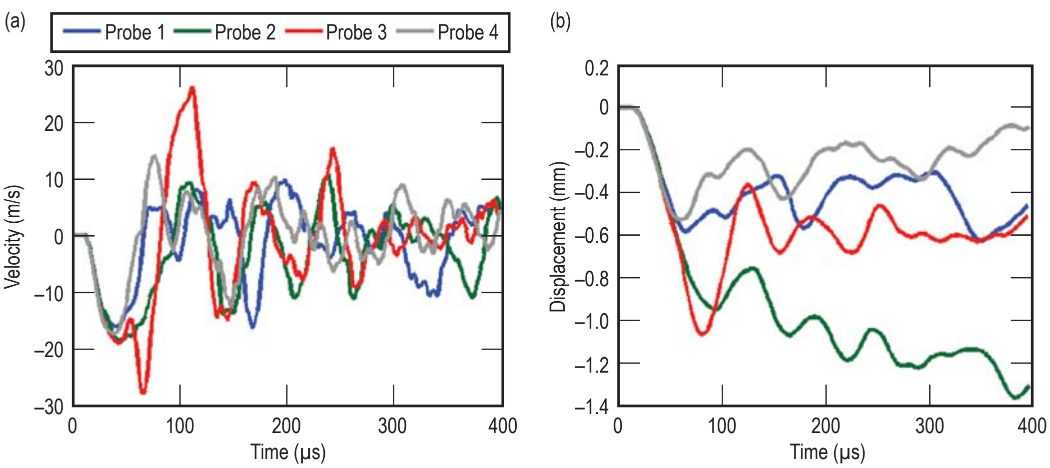


Figure 3. (a) Velocity and (b) displacement of the monitored surfaces as a function of time. Velocity is calculated by applying a sliding FFT to the raw data in Fig.2, then scaling the transformed results. Displacement is calcualted by integrating the velocity data with respect to time.